# An Improved Direct Forcing Immersed Boundary Method for Simulating Floating Objects

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## ABSTRACT

Accurate, efficient, and validated calculations of the fluid-floating object interactions are immensely challenging and of vital importance to computational fluid dynamics (CFD) based solvers. Immersed boundary method (IBM), as a non-boundary-conforming method, was initially introduced by Peskin (1972) to simulate fluid-structure interaction (FSI) problems associated with human heart valves. The method then has gained attention in recent years due to its simplicity and flexibility, and several variants of this method have been developed to improve its accuracy and enhance its applicability to realistic problems. Fadlun et al. (2000) introduced a direct formulation of the force term. In this method, the velocity boundary condition is imposed on a given immersed boundary. This scheme, called direct forcing, can be used with larger time steps contrary to Peskin's method. The earliest applications of the direct forcing method treat stationary bodies. When it comes to moving objects, spurious force oscillation occurs due to sudden changes in the relative position between the fixed grid and arbitrarily moving object. Uhlmann (2005) then combined the discrete delta function kernels with direct forcing formulations to resolve the spurious force oscillation problem. In this approach, the Eularian velocities at the fixed grid points are first interpolated to Lagrangian points on the immersed boundary via a regularized Dirac delta function. Then the local forcing term is calculated for corresponding desired velocity which depends on the boundary conditions on the fluid-solid body interface. Finally, the local forcing is transferred to surrounding Eularian locations using the regularized Dirac delta function. Similarly, this back-and-forth mechanism between Lagrangian and Eulerian locations to transfer the quantities is also used by Kempe et al. (2012, 2015). In addition, Kempe et al. (2015) showed that even when the tangential force is set to zero, the standard direct forcing procedure leads to artificial shear stress at the fluid-solid body interface. Because the fluid velocity and viscosity are considered the same inside and outside of the immersed boundary. Therefore, an additional forcing was applied in the tangential directions and so the tangential velocity component could be modified. As a result, the shear stress at the solid body surface is set to zero, explicitly. Nevertheless, the smoothing process smear fluid-solid body interface and some ad hoc treatments implemented into IBM methods can lead to undesirable problems.

In this paper, an enhancement for a direct forcing immersed boundary method is proposed. The open-source CFD code REEF3D::CFD (Bihs et al. 2016) is used for numerical calculations. To calculate rigid-body motion, a continuous direct forcing method is available in REEF3D (Martin et al. 2021). The main intention of the proposed method is to decrease the blurriness of the fluid-solid interface and increase the accuracy of the tangential velocity calculations in the vicinity of the solid body. On this premise, the paper starts with demonstrating the weakness of the original formulations of Direct-Forcing IBM in REEF3D::CFD by simulating a benchmark problem. The proposed method is then tested with the same problem and is validated for different benchmark problems. The numerical results are compared with experimental results, and the performance of the new method is presented.

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